



Review

Endovascular management of axillo-subclavian arterial injury: A review of published experience[☆]

Joseph J. DuBose^{a,*}, Ravi Rajani^b, Ramy Gilani^c, Zachary A. Arthurs^d, Jonathan J. Morrison^e, William D. Clouse^f, Todd E. Rasmussen^e

For the Endovascular Skills for Trauma and Resuscitative Surgery (ESTARS) Working Group

^a University of Maryland Medical System, R Adams Cowley Shock Trauma Center, United States Air Force Baltimore Center for the Sustainment of Trauma and Readiness Skills (CSTARS), United States

^b Division of Vascular Surgery, Department of Surgery, Emory University School of Medicine, United States

^c Division of Vascular Surgery and Endovascular Therapy of the Michael E. DeBakey, Department of Surgery at Baylor College of Medicine, United States

^d San Antonio Military Medical Complex, Fort Sam Houston, TX, United States

^e United States Army Institute for Surgical Research, Fort Sam Houston, TX, United States

^f David Grant Medical Center, Travis Air Force Base, CA, United States

ARTICLE INFO

Article history:
Accepted 3 August 2012

Keywords:
Calmodulin
Chlorpromazine
Leaf senescence
Salt stress
Sweet potato

ABSTRACT

Background: The role of endovascular treatment for vascular trauma, including injury to the subclavian and axillary arteries, continues to evolve. Despite growing experience with the utilization of these techniques in the setting of arteriosclerotic and aneurysmal disease, published reports in traumatic subclavian and axillary arterial injuries remain confined to sporadic case reports and case series.

Methods: We conducted a review of the medical literature from 1990 to 2012 using Pubmed and OVID Medline databases to search for all reports documenting the use of endovascular stenting for the treatment of subclavian or axillary artery injuries. Thirty two published reports were identified. Individual manuscripts were analysed to abstract data regarding mechanism, location and type of injury, endovascular technique and endograft type utilized, follow up, and radiographic and clinical outcomes.

Results: The use of endovascular stenting for the treatment of subclavian (150) or axillary (10) artery injuries was adequately described for only 160 patients from 1996 to the present. Endovascular treatment was employed after penetrating injury (56.3%; 29 GSW; 61 SW), blunt trauma (21.3%), iatrogenic catheter related injury (21.8%) and surgical injury (0.6%). Injuries treated included pseudoaneurysm (77), AV fistula (27), occlusion (16), transection (8), perforation (22), dissection (6), or other injuries otherwise not fully described (4). Initial endovascular stent placement was successful in 96.9% of patients. Radiographic and clinical follow up periods ranging from hospital discharge to 70 months revealed a follow up patency of 84.4%. No mortalities related to endovascular intervention were reported. New neurologic deficits after the use of endovascular modalities were reported in only one patient.

Conclusion: Endovascular treatment of traumatic subclavian and axillary artery injuries continues to evolve. Early results are promising, but experience with this modality and data on late follow up remain limited. Additional multicenter prospective study and capture of data for these patients is warranted to further define the role of this treatment modality in the setting of trauma.

Published by Elsevier Ltd.

[☆] Disclaimer: The opinions contained herein do not reflect the opinions or position of the Department of Defense, the United States Army or the United States Air Force.

* Corresponding author at: Air Force CSTARS – Baltimore, University of Maryland Medical System/R Adams Cowley Shock Trauma, 22 South Greene Street, T5R46, Baltimore, MD 21201, United States. Tel.: +1 410 328 0241.

E-mail address: jjd3c@yahoo.com (J.J. DuBose).

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE 01 NOV 2012		2. REPORT TYPE N/A		3. DATES COVERED -	
4. TITLE AND SUBTITLE Endovascular management of axillo-subclavian arterial injury: A review of published experience.				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) DuBose J. J., Rajani R., Gilani R., Arthurs Z. M., Morrison J. J., Clouse D. W., Rasmussen T. E.,				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) United States Army Institute of Surgical Research, JBSA Fort Sam Houston, TX				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release, distribution unlimited					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT UU	18. NUMBER OF PAGES 8	19a. NAME OF RESPONSIBLE PERSON
a REPORT unclassified	b ABSTRACT unclassified	c THIS PAGE unclassified			

Contents

Introduction	1786
Materials and methods	1786
Results	1786
Discussion	1789
Conclusion	1791
Author contributions	1791
References	1791

Introduction

Traumatic injuries of the subclavian or axillary artery continue to be associated with high morbidity and mortality rates,¹ requiring timely and effective management in the earliest phases after injury in order to optimize outcome. The management of these injuries has traditionally required operative surgical intervention. Open surgical approaches are, however, challenging due to the tightly confined arrangement of key neurovascular anatomical relationships of the apical thorax. This, combined with the dense overlying bony anatomy, precludes rapid surgical access to injured structures and confounds the ability to adequately control vascular structures for repair without causing injury to adjacent structures.

The emergence of endovascular modalities offers an alternative to traditional surgical management of select subclavian and axillary artery traumatic lesions. Since their introduction, endovascular technologies have seen expanded use for a variety of indications, including the treatment of these injuries. Published experience to date, however, remains limited. Reports of successful endovascular treatment of traumatic subclavian and axillary artery trauma remain confined to case reports and small series documented in the literature. Our study is designed to summarize the experience to date with endovascular treatment for these injuries through a review of the available medical literature.

Materials and methods

We conducted a systematic review of the English speaking medical literature using Pubmed (www.pubmed.gov, accessed 1 Feb 2012) service of the National Library of Medicine/National Institutes of Health and the OVID Medline databases (Copyright © 2000–2011 Ovid Technologies) to identify all case reports and case series of subclavian and/or axillary artery endovascular management after injury to these vessels, either from trauma or iatrogenic injury. Specifically, the search terms “subclavian” or “axillary” were combined with “artery” and “trauma” or “injury” to identify articles for review. The following criteria were used to select studies to be included for analysis: adequate information regarding mechanism, location, and type of injury; use and type of stenting devices performed; type and timing of clinical and radiographic follow up; radiographic and clinical outcomes.

Results

Forty four published reports with endovascular treatment of subclavian or axillary artery injuries were identified. Twelve of these publications lacked sufficient information for inclusion and were excluded, leaving 32 published reports or case series available for review over the study time period of 1996–2012.^{2–33}

The use of endovascular modalities after subclavian or axillary artery injuries was described in 160 patients (150 subclavian; 10 axillary) (Table 1), 78.8% of which were male. Age ranged from 10 to 93 years. Stenting was most commonly utilized after penetrat-

ing injury (56.3%; 29 Gunshot wounds; 61 stab wounds); followed by blunt trauma (21.3%), iatrogenic venous catheter insertion related injury (21.8%) and surgical injury (0.6%). Lesions treated included pseudoaneurysm ($n = 77$, 48.1%) (Figs. 1 and 2); arteriovenous fistula ($n = 27$, 16.9%), perforation ($n = 22$, 13.7%), occlusion ($n = 16$, 10.0%), partial or complete transection ($n = 8$; 5.0%), dissection ($n = 6$, 2.5%) and four other lesions not definitively characterized (Table 2). Seventeen of these lesions were treated in a delayed fashion after missed diagnosis or distant injuries, with the remaining majority undergoing endovascular intervention acutely during initial hospitalization.

A wide variety of stent devices were utilized during endovascular management of injuries, including Corvita [Corvita Corporation, Boston Scientific, Miami, FL], Palmaz [Cordis Corporation, Miami Lakes, FL] or Giaturo Z stents [Cook Medical, Bloomington, IN] covered with Polytetrafluoroethylene (PTFE) crimped grafts ($n = 11$); Palmaz [Cordis Corporation, Miami Lakes, FL] dacron stents ($n = 7$); Corvita [Corvita Corporation, Boston Scientific, Miami, FL] endoluminal grafts ($n = 5$); Wallstent [Boston Scientific, Watertown, MA, USA] endoluminal stents ($n = 7$); Wallgraft [Boston Scientific, Watertown, MA, USA] endografts ($n = 43$); Hemobahn stent grafts [W.L. Gore and Associates, Flagstaff, AZ] ($n = 20$); Jostent stent grafts [Jomed AB, Rangendingen, Germany] ($n = 5$); Passager grafts [Boston Scientific, Watertown, MA, USA] ($n = 1$); Viabahn stent grafts [W.L. Gore and Associates, Flagstaff, AZ] ($n = 8$); Advanta covered stents [Atrium Interventional, Hudson, New Hampshire] ($n = 1$); iCast stents [Atrium Interventional, Hudson, New Hampshire] ($n = 3$); Luminexx stents [Bard, Murray Hill, NJ] ($n = 3$); Fluency endografts [Bard, Murray Hill, NJ] ($n = 34$); and either Stecker Palmaz [Cordis Corporation, Miami Lakes, FL] ($n = 2$) or other bare metal stents not fully described ($n = 7$).

Intervention was accomplished under local/monitored anaesthesia care without general anaesthetic in 56.9% ($n = 91$) of described cases, with only 16.3% ($n = 26$) described as requiring general anaesthesia. The method of anaesthesia was not adequately described in the remainder of cases. Vascular access sites for endovascular intervention also varied between reports. Femoral was the preferred site in most cases and series, utilized in 66.9% of cases ($n = 107$). This was followed by brachial (18.8%, $n = 30$), combined femoral and brachial approaches (8.1%; $n = 13$) and axillary sites (1.3%, $n = 2$). For 8 cases the access site for stent deployment was not explicitly outlined. In only one case of a proximal right subclavian injury was a technique incorporating placement of a balloon in the proximal carotid to protect against potential embolization with stent expansion described.⁷ Procedure times required for the conduct of endovascular intervention were described in only 7 reports. Among these, reported procedure times averaged approximately 2 h, with one case series¹⁶ documenting a mean completion time of 27 min for 7 cases.

There were five failures of attempted stent placement reported during the initial procedural attempt. One patient had initial attempt at stent placement abbreviated prior to stent introduction due to patient instability.²⁹ In this case, an

Table 1

Description of published studies documenting experience with endovascular stenting of subclavian and/or axillary injuries.

Year	Study	No. patients	Mechanism	Type of injury (n)	Gender (n)	Devices utilized (# patients)
1996	Patel AV, et al., J Endovac Surg	6	Penetrating (5) [GSW (4); SW (1)] Iatrogenic catheter (1)]	Pseudoaneurysm (5) AV fistula (1)	Male (5) Female (1)	Palmaz stent with hand constructed PTFE sewn coverage (6)
1996	Gomez-Jorge JT, et al., J Vasc Interv Radiol	1	Iatrogenic Catheter (1)	AV fistula (1)	Male (1)	Corvita covered stent (1)
1997	Criado E, et al., Ann Vasc Surg	2	Penetrating (2) [GSW (1); SW (1)]	Pseudoaneurysm (1) AV fistula (1)	Male (2)	PTFE covered Z stents (1); PTFE-covered Palmaz stents (1)
1998	Babatasi F, et al., J Trauma	1	Blunt (1)	Pseudoaneurysm (1)	Male (1)	Palmaz stents X 2 (1)
1999	Parodi JC, et al., Ann Vasc Surg	12	Penetrating (7) [GSW (7)] Iatrogenic catheter (5)]	Pseudoaneurysm (4) AV fistula (8)	Male (12)	Palmaz dacron (5); Palmaz PTFE (1); Corvita endoluminal graft (5); Corvita + Palmaz PTFE (1)
1999	Janne d'Othee B, et al., Cardiovasc Intervent Radiol	1	Blunt (1)	Occlusion (1)	Male (1)	Wallstent (1)
2000	Stecco K, et al., J Trauma	1	Penetrating (1) [GSW (1)]	Partial transection (1)	Male (1)	PTFE covered Gianturco Z-Stent (1)
2001	Strauss DC, et al., J Endovasc Ther	2	Penetrating (2) [SW (2)]	Occlusion (2)	Male (2)	Wallgraft (2)
2001	Brandt MM, et al., J Trauma	2	Blunt (2)	Dissection (1) Transection (1)	Male (2)	Wallstent (2)
2001	Bartorelli AL, et al., J Endovasc Ther	2	Iatrogenic catheter (2)	Perforation (2)	Male (1) Female (1)	Hemobahn (2)
2003	Renger RJ, et al., J Trauma	1	Blunt (1)	Pseudoaneurysm (1)	Female	Wallgraft (1)
2003	Schoder M, et al., J Endovasc Ther	8	Iatrogenic catheter (8)	Perforation (8)	Male (3) Female (5)	Hemobahn (7); Jostent (1); Passager (1)
2003	Xenos ES, et al., J Vasc Surg	7	Penetrating (3) [GSW (2), SW (1)] Blunt (1) Iatrogenic catheter (3)	Perforation (1) Pseudoaneurysm (3) AV fistula (3)	Male (3) Female (4)	Wallgraft (7)
2005	Vinces FY, et al., J Thorac Cardiovasc Surg	1	Penetrating (1) [GSW (1)]	AV fistula (1)	Male (1)	Viabahn (1)
2005	Castelli P, et al., Injury	7	Penetrating (1) [SW (1)] Blunt (1) Iatrogenic catheter (4) Iatrogenic surgical (1)	Pseudoaneurysm (4) Dissection (2) Partial transection (1)	Male (3) Female (4)	Wallstent; Wallgraft; Fluency (# for each not described)
2007	Cipanio S, et al., Minerva Anesthesiol	1	Iatrogenic catheter (1)	Perforation (1)	Female (1)	Advanta (1)
2007	Bukhari HA, et al., Can J Surg	1	Blunt (1)	Pseudoaneurysm (1)	Female (1)	Jostent (1)
2007	Stokkeland PJ, et al., J Vasc Interv Radiol	1	Blunt (1)	Perforation (1)	Male (1)	Hemobahn (1)
2007	Piffaretti G, et al., Injury	4	Blunt (4)	Pseudoaneurysm (1) Dissection (3)	Male (4)	Wallgraft (1); Luminexx (3)
2007	Kapadia S, et al., J Cardiothorac Vasc Anesth	1	Iatrogenic catheter (1)	Pseudoaneurysm (1)	Female (1)	Wallgraft (1)
2008	Testerman GM, et al., South Med J	1	Penetrating (1) [GSW (1)]	Pseudoaneurysm (1)	Male (1)	iCast (1)
2008	Derom A, et al., Acta Chir Belg	1	Blunt (1)	Pseudoaneurysm (1)	Male (1)	Hemobahn (1)
2008	du Toit DF, et al., J Vasc Surg	57	Penetrating (57) [GSW (4); SW (53)]	Pseudoaneurysm (42) AV fistula (12) Occlusion (3)	Male (52) Female (5)	Hemobahn (9); Wallgraft (20); Fluency (27); Custom made Palmaz stent with sutured PTFE (1)
2008	Cohen JE, et al., J Neurol Sci	6	Penetrating (6) [GSW (4); SW (2)]	Pseudoaneurysm (6)	Male (6)	Jostent (3); Wallgraft (2); Fluency (1)
2009	Pikwer A, et al., J Vasc Endovasc Surg	3	Iatrogenic catheter (3)	Perforation (3)	Female (3)	Fluency (2); Viabahn (1)
2009	Michaluk BT, et al., Ann Vasc Surg	1	Blunt (1)	Pseudoaneurysm (1)	Male (1)	Viabahn (1)
2010	Cayne NS, et al., Ann Vasc Surg	2	Iatrogenic catheter (2)	Perforation (2)	Not described (2)	iCast (2)
2010	Carrick MM, et al., Am J Surg	6	Penetrating (4) [GSW (4)] Blunt (2)	partial transection (1) Pseudoaneurysm (1) Not described (4)	Male (6)	Wallgraft (6)
2010	Chemelli AP, et al., J Vasc Interv Radiol	4	Iatrogenic catheter (4)	Perforation (4)	Male (2) Female (2)	Fluency (3); Wallgraft (1)

Table 1 (Continued)

Year	Study	No. patients	Mechanism	Type of injury (n)	Gender (n)	Devices utilized (# patients)
2011	Carrafiello G, et al., J Vasc Interv Radiol	6	Blunt (6)	Transection (3) Occlusion (1) Pseudoaneurysm (2)	Male (5) Female (1)	Wallgraft (2); Fluency (3); Strecker Bare Stent (1)
2011	Stefanczyk L, et al., Cardiovasc Intervent Radiol	1	Blunt (1)	Pseudoaneurysm (1)	Female (1)	Viabahn (1)
2011	Shalhub S, et al., J Trauma	10	Blunt (10)	Occlusion (9) Transection (1)	Male (8) Female (2)	Wallstent (4); Viabahn (5); Bare metal stent (1)

GSW = gunshot wound; SW = stab wound.

Table 2

Types of subclavian and axillary artery injuries treated with stenting.

Injury type	n	Percent
Pseudoaneurysm	77	48.1
Arteriovenous fistula	27	16.9
Perforation	22	13.7
Occlusion	16	10.0
Partial or complete transection	8	5.0
Dissection	6	3.8
Not fully described	4	2.5
Total	160	100.0

occlusive balloon was advanced proximal to the lesion, the patient was resuscitated in the ICU, and underwent successful stent placement on hospital day 2. Four other patients had acute failure of stent placement or failure of stent to adequately cover the lesion which necessitated conversion to urgent open repair.^{29,33} Overall, successful initial endovascular stent placement, defined as complete occlusion of the lesion with restoration of normal blood flow at the conclusion of initial procedure, occurred in 96.9% (155 of 160) of patients treated.

Six procedure related complications, not including failure to achieve effective stent deployment, were reported; three access site related, two embolic events, and one immediate peri procedural mortality. Access site complications included brachial phlebitis with severe lymphangitis and fever requiring heparin and antibiotics,⁷ brachial pseudoaneurysm after failure of percutaneous closure device requiring open repair and the development¹⁷ of an intimal flap at a femoral puncture site.²⁴ Embolic events consisted of on distal brachial embolization after stent deployment requiring brachial cutdown and embolectomy¹¹ and one patient

with probable stent deployment related cerebral infarction.¹³ The only reported peri procedural mortality reported was a death occurring in the angiography suite after successful deployment of an endovascular stent had been completed.²⁹

Details of post operative anticoagulation plans were outlined in only nine instances. These varied highly between reports. Fluindione for 15 days,⁷ sub cutaneous heparin for 24 h,^{20,30} and sub cutaneous heparin for several weeks^{13,31} were all utilized. Antiplatelet agents, in the form of clopidogrel 75 mg daily, ticlopidine 120 mg daily or aspirin 100 mg per day were also advocated by various authors, either in isolation or combined form, for periods varying from 3 months to lifelong use.^{13,20,25,30,31}

Follow up periods among individual reports and case series varied from hospital discharge to 70 months. The type of follow up, likewise, was diverse among the 32 reports. These included clinical exam alone (3); clinical exam combined with Duplex (16) and/or Computed Tomographic Angiography (CTA) (7); clinical exam plus plain radiography or fluoroscopy to rule out stent fracture/stent malposition (2) and even clinical exam with routine angiography (2). In two reports, the type of follow up was not explicitly outlined, although patency was assured in the description of their outcomes. Overall, radiographic and clinical follow up periods ranging from hospital discharge to 70 months were reported, yielding a follow up asymptomatic patency rate of 84.4% for the duration of available follow up.

On follow up, no device related infections, migrations or acute limb threatening ischaemic events were reported among the 160 reported cases. One stent fracture, necessitating repeat endo graft deployment, was identified.² No new neurologic adverse events (excluding the aforementioned intra procedural stroke) were noted. During follow up, 10 patients (6.3%) were noted to have stent fracture (1), stenosis or occlusion (9) requiring repeat

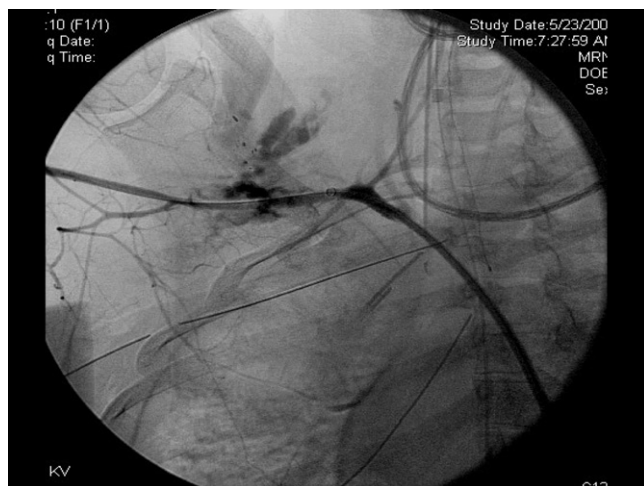


Fig. 1. Partial transection of axillary artery on diagnostic angiogram.



Fig. 2. Partial transection of axillary artery from Fig. 1 after endograft exclusion.

Table 3

Stent related outcomes.

Injury type	n	Percent
Patency for duration of available follow-up	135	84.4
Stent fracture, occlusion or stenosis requiring repeat endovascular therapy to restore patency	10	6.3
Asymptomatic occlusion or stenosis \geq 50%, no repeat intervention	7	4.4
Acute failure of stent attempt or stent coverage requiring urgent open conversion	5	3.1
Persistent endoleak requiring repeat endovascular intervention	2	1.2
Delayed symptomatic occlusion requiring open surgical bypass	1	0.6
Total	160	100.0

endovascular intervention in the form of thrombolysis, angioplasty or repeat stenting to successfully restore patency. Two patients (1.2%) required repeat endovascular intervention for the treatment of persistent endoleaks. Seven patients (4.4%) were found to have asymptomatic stenosis of at least 50% luminal narrowing that required no additional intervention. Only one patient required delayed open surgical bypass, which was conducted for treatment of symptomatic occlusion nine months after initial stent placement¹⁴ (Table 3).

Discussion

Injuries to the subclavian and axillary arteries continue to be associated with high rates of morbidity and mortality. In one of the landmark series on these injuries, Demetriades et al. at Los Angeles County + University of Southern California Hospital³⁴ examined penetrating subclavian and axillary injuries, identifying 79 patients with these injuries over approximately 4 years. The associated overall mortality was 34.2%. Even after excluding those patients in extremis requiring resuscitative thoracotomies, mortality remained considerable, at 14.8%.

The traditional surgical management of these injuries requires appropriate familiarity of the arterial anatomy, as well as an appreciation for the complex relationships between the vasculature and other anatomical structures within this confined space. Extending from its origin (innominate artery on the right and aortic arch on the left), the first portion of the subclavian artery extends to the medial border of the anterior scalene muscle. It then courses posterior to this muscle as the second portion of the vessel. Finally, the third portion of the subclavian artery extends from the lateral edge of the anterior scalene to the outer border of the first rib. Beyond the first rib to the lower border of the tendon of the Teres major muscle, the vessel becomes the axillary artery. Along this course the subclavian and axillary arteries give rise to a number of named branches, including the proximal vertebral artery, which supply a variety of skeletal, muscular and nerve tissues of the upper thorax and shoulder (Fig. 3). The open surgical management of these vessels, particularly when compromised by the presence of associated haematoma and soft tissue injury in the setting of trauma, presents a considerable challenge to even the most skilled of trauma providers.

With the introduction of endovascular techniques for applications related to vascular injury, these less invasive modalities have increasingly been safely utilized in the treatment of select patients with a variety of peripheral vascular injuries.³⁵ Success rates comparable to our presently reported findings have been reported following endovascular management of vascular injury at a variety of sites, including carotid, subclavian, femoral and iliac

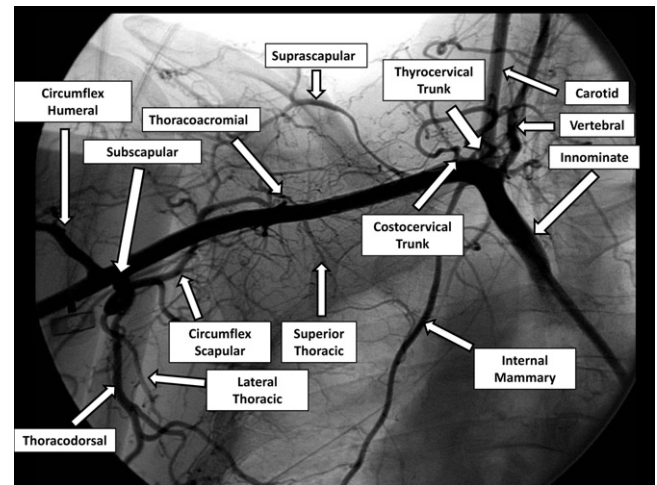


Fig. 3. Anatomy of the subclavian and axillary arteries, right-sided vasculature shown.

arteries.^{34,36,37} Subsequently, several investigators have undertaken comparisons of outcomes between open and endovascular treatment of vascular trauma for a variety of lesions. Although such comparisons possess some inherent limitations, early results have proven promising. In one recent study, White et al.,³⁷ conducted a comparison, facilitated by Bayesian analysis, of open and endovascular iliac artery repair. These investigators found that emergent stenting of amenable iliac arterial injuries resulted in fewer operative/post operative complications and both lower post procedure and all cause mortality rates than historical open counterparts.

Three of the series in our presently reported review undertook limited comparisons of open versus endovascular treatment specifically of subclavian and axillary arteries.^{14,29,33} Xenos et al.,¹⁴ conducted a retrospective examination of patients treated for trauma to these vessels due to both blunt and penetrating mechanisms over a 5 and half year period at the University of Tennessee. These investigators identified 7 of 27 patients who underwent endovascular treatment, noting that endovascular repair was associated with significantly shorter operative time ($p = 0.04$) and less blood loss ($p = 0.01$) than open counterparts. In a subsequent report by Carrick et al at the Baylor College of Medicine,²⁹ the investigators identified 6 patients undergoing endovascular repair over a 2 year period. They found that procedural related brachial plexus injury occurred in one of three open surgical counterparts, but in none of the endovascular repair patients. The most recent such comparison, conducted by Shalhub and co investigators from University of Washington and South west Washington Medical Centre, consisted of a retrospective review over a decade. These investigators found that 12 patients undergoing endovascular treatment of thoracic outlet arterial injuries had shorter operative time (149 min vs. 230 min; $p = 0.03$) and less blood loss (50 mL vs. 1225 mL; $p = 0.03$) than counterparts selected for open operative intervention.

Despite these early encouraging results, definitive answers to important questions regarding the utilization of endovascular modalities in the treatment of subclavian and axillary vascular injuries remain. Ideal patient selection requires additional investigation. The aforementioned review by White et al.³⁷ noted that, among iliac artery injury patients currently selected for endovascular treatment, those selected tended to be older and possess more co morbidities. Our present review demonstrates that the majority of endovascular interventions can be completed without the risk associated with general anaesthesia. This

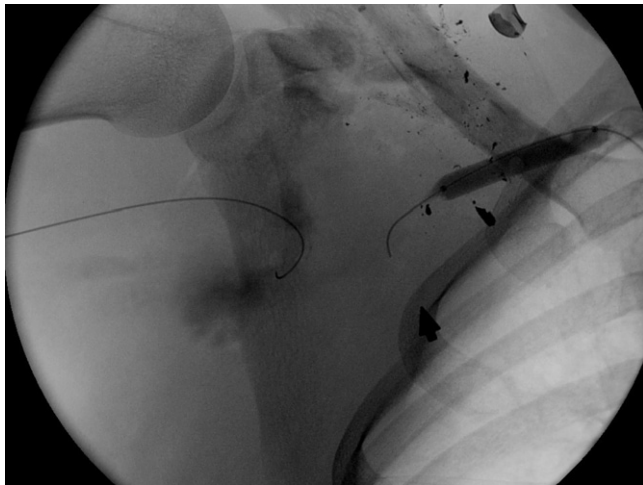


Fig. 4. Arterial transection with proximal balloon occlusion utilization via femoral access and "rendezvous" access via brachial site to traverse lesion.

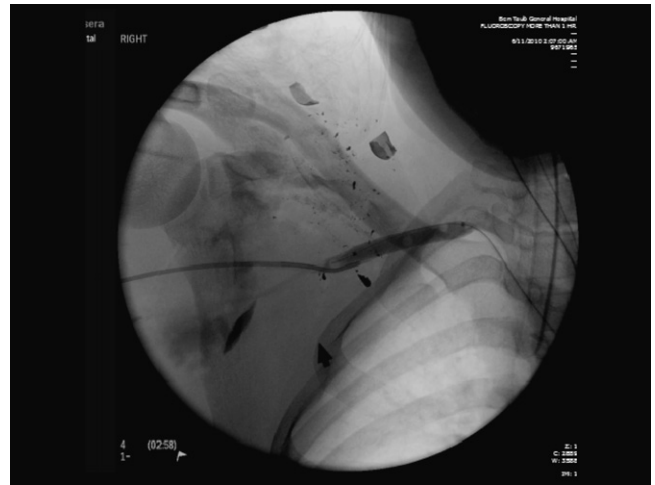


Fig. 5. Successful traverse of lesion following "rendezvous" technique from Fig. 4.

combined with the aforementioned findings that the procedural times may be shorter and procedural blood loss less, may be suggestive that endovascular approaches are ideal for those stable patients with higher operative risk due to comorbidities. As both technological capabilities and experience continue to improve, however, many investigators are utilizing these same findings of shorter procedural times and less blood loss to validate exploring the application of endovascular treatment of these injuries for a broader spectrum of patients, including more urgent cases. Indeed, as endovascular balloon occlusion techniques continue to evolve, it may prove beneficial to utilize endovascular approaches for even select unstable patients.^{38,39} In these instances, endovascular approaches can facilitate either rapid coverage of the causative lesion, or balloon tamponade and subsequent endo graft placement either during the initial procedure, or in a delayed fashion after resuscitation (Figs. 4 and 5). We noted in our present review of the literature that such a delayed approach was utilized successfully in a hemodynamically unstable patient by Carrick et al.²⁹ at the Baylor College of Medicine.

Additional technical considerations involve the timing of intervention. The majority of described cases in this review were conducted during the initial hospitalization and in the likely presence of fresh thrombus associated with the vascular injury. The embolic risk of endo graft deployment in this setting appears to be minimal, with only two events in our present series – one probable stent related stroke¹³ and one distal embolization of brachial artery.¹¹ The true risk of these events, however has not been well established. In our present series only one distal protective occlusive balloon was utilized during endo graft deployment; placed in the proximal carotid artery during treatment of a right proximal subclavian injury.⁷ The value of such protective measures, however, has not been examined in this setting.

Likewise, among the series available for review, rare mention is made of the potential ramifications of branch vessel coverage. There remains the potential that coverage of the origin of the vertebral artery, in particular, may lead to thrombosis of the basilar artery and compromise of cerebral circulation. The importance of these considerations for endovascular treatment of subclavian and axillary artery injuries has not, however, been well examined.

It should also be considered that there may be a difference in the need for endo graft exclusion based upon injury mechanism. Although for the purpose of our present review catheter related injuries were included in analysis, these types of injuries may

benefit from the utilization of a unique algorithm to their treatment. In these instances, endo graft coverage may only be required after exhaustion of other endovascular interventions, including duplex or angiographic assisted compression and evaluation for the feasibility of percutaneous device assisted closure. At least two groups of authors reporting series of catheter related injuries in our review have proposed such algorithms,^{28,30} but these approaches have not been validated and require additional study.

In addition to selection criteria, there remain technical components of treatment that must be better elucidated in order to develop ideal, but flexible algorithms for endovascular intervention. The significance of injury characteristics and anatomical considerations must be more comprehensively studied in order to better define the role of these factors in both feasibility of endovascular intervention and vascular access approaches. In our present review there was considerable variation in the vascular site chosen for guidewire and device introduction, with both femoral and brachial sites utilized in isolation or in combined approaches. As suggested by at least one group of investigators,¹⁴ the brachial artery may provide a more direct, shorter, less tortuous approach for lesions that are deemed unlikely to prove amenable to crossing with a guidewire in the conduct of stent deployment. In other instances, dual femoral and brachial access "rendezvous" techniques may be required for adequate guidewire manipulation and endo graft positioning.^{14,31}

Many of these choices may be guided by the ongoing evolution in endovascular technology. In our present study, at least 15 different devices were utilized, with several patients requiring multiple different types of devices for lesion exclusion. In an expanding market, the performance of these various devices has not yet been adequately compared. The majority of these devices, however, can safely and effectively be employed in a traditional operative theatre with modern portable fluoroscopic imaging technology. As patient condition and facility capabilities dictate, they can also be utilized in conjunction with open surgical techniques. The utility of combined/hybrid procedures incorporating open and endovascular techniques for either primary treatment or to address distal embolic complications of primary injury, however, remains to be critically considered in a larger study.^{40–42} Overall, additional study is required to better define those lesions that may prove more amenable to the various approaches; as well as the optimal devices and algorithms to be utilized for these procedures.

There are also a number of elements of post procedural care that may benefit from research and standardization, including the management of associated haematoma, the role of subsequent anticoagulation and ideal follow up modalities. While there remains the possibility that haematoma associated with initial injury may have adverse effects on the brachial plexus due to compression, none of the reports available demonstrated any issues of this type after endovascular repair. The use of peri and post procedural anticoagulation practices was only sporadically described in available reports. Likewise, our review found that follow up practices were not uniform, but included various configurations of clinical exam, phone interviews, duplex, computed tomographic angiography and even traditional angiography.

Until well defined selection criteria and optimal management algorithms for the use of endovascular stenting of vascular injuries are validated, the reality of utilization may continue to be defined by uncertainties in patient selection. In illustration of this point, a recent retrospective examination conducted by Danetz et al.⁴³ at the Medical College of Virginia found that among penetrating injuries to the axillary and subclavian vessels only 42.5% were deemed potentially treatable with endovascular therapy. The most common contraindications to endovascular therapy described by the investigators were haemodynamic instability, vessel transection, and absence of an adequate proximal vascular fixation site.

There are several important limitations to our present report. Any review of the literature, no matter how systematically conducted, will inherently suffer from both reporting bias and retrospective limitations. A limitation not previously outlined in this discussion remains the failure of the majority of articles to adequately outline the background of the providers actually conducting these procedures. Discerning if these procedures were conducted by cardiologists, interventional radiologists or vascular surgeons might improve the ability to document the evolution of endovascular capabilities for trauma across multiple disciplines. Additionally, the time from injury to treatment was not universally clear across reports. These temporal relationships may prove important in treatment selection and management. Finally, the reporting of peri procedural complications was not uniform or detailed across reviewed reports. The details of these adverse events are important in treatment selection algorithms.

Despite these limitations and the need for increased study on endovascular treatment of subclavian and axillary arterial injuries, early results appear promising from our review. Overall, demonstrated successful initial endovascular device placement occurred in 96.9% of patients treated in available reports, with longer term patency in 84.4% over a follow period varying from hospital discharge to 70 months. Rates of device related complications were also encouraging; with no device related infections, migrations or acute limb threatening ischaemic events reported. Among the 11.8% (20 of 160) of patients with stenosis, endoleak or occlusion identified on follow up, only 13 required any repeat treatment. Even for patients requiring subsequent intervention on follow up, the majority (92.3%; 12 of 13) proved amenable to techniques that did not require open surgical intervention; a successful endovascular re intervention rate consistent with suggested expectations from published experiences.^{44,45}

Conclusion

Endovascular treatment of traumatic subclavian and axillary artery injuries continues to evolve. Despite uncertainties in patient selection and optimal management algorithms, early results are promising. Experience with this modality and data on late follow up, however, remain limited. Additional multicenter prospective study and capture of data for these patients is warranted, in order

to further define the role of this treatment modality in the setting of trauma.

Author contributions

All of the listed authors were actively engaged in study design, analysis and interpretation of data, as well as construction and editing of the final manuscript report for this work.

Conflict of interest statement

The authors have no conflicts of interest to disclose, financial or otherwise that are associated with this work.

References

- Demetriades D, Asensio JA. Subclavian and axillary vascular injuries. *Surgical Clinics of North America* 2001;**81**(December (6)):1357–73. xiii.
- Patel AV, Marin ML, Veith FJ, Kerr A, Sanchez LA. Endovascular graft repair of penetrating subclavian artery injuries. *Journal of Endovascular Surgery* 1996;**3**(November (4)):382–8.
- Gomez-Jorge JT, Guerra Jr JJ, Scagneli T, Mendez KR, Yrizarry JM. Endovascular management of a traumatic subclavian arteriovenous fistula. *Journal of Vascular and Interventional Radiology* 1996;**7**(July–August (4)):599–602.
- Criado E, Marston WA, Ligush J, Mauro MA, Keagy BA. Endovascular repair of peripheral aneurysms, pseudoaneurysms, and arteriovenous fistulas. *Annals of Vascular Surgery* 1997;**11**(May (3)):256–63.
- Babatasi G, Massetti M, Le Page O, Theron J, Khayat A. Endovascular treatment of a traumatic subclavian artery aneurysm. *Journal of Trauma* 1998;**44**(March (3)):545–7.
- Parodi JC, Schonholz C, Ferreira LM, Bergan J. Endovascular stent-graft treatment of traumatic arterial lesions. *Annals of Vascular Surgery* 1999;**13**(March (2)):121–9.
- Janne d'Othee B, Rousseau H, Otal P, Joffre F. Noncovered stent placement in a blunt traumatic injury of the right subclavian artery. *Cardiovascular and Interventional Radiology* 1999;**22**(September–October (5)):424–7.
- Stecco K, Meieir A, Seiver A, Dake M, Zarins C. Endovascular stent-graft placement for treatment of traumatic penetrating subclavian arterial injury. *Journal of Trauma* 2000;**48**(May (5)):948–50.
- Strauss DC, du Toit DF, Warren BL. Endovascular repair of occluded subclavian arteries following penetrating trauma. *Journal of Endovascular Therapy* 2001;**8**(October (5)):529–33.
- Brandt MM, Kazanjian S, Wahl WL. The utility of endovascular stents in the treatment of blunt arterial injuries. *Journal of Trauma* 2001;**51**(November (5)):901–5.
- Bartorelli AL, Trabattini D, Agrifoglio M, Galli S, Grancini L, Spirito R. Endovascular repair of iatrogenic subclavian artery perforations using Hemobahn stent-graft. *Journal of Endovascular Therapy* 2001;**8**(August (4)):417–21.
- Renger RJ, de Bruijn AJ, Aarts HC, van der Hem LG. Endovascular treatment of a pseudoaneurysm of the subclavian artery. *Journal of Trauma* 2003;**55**(November (5)):969–71.
- Schoder M, Cejna M, Holzenbein T, Bischof G, Lomoschitz F, Funovics M, et al. Elective and emergent endovascular treatment of subclavian artery aneurysms and injuries. *Journal of Endovascular Therapy* 2003;**10**(February (1)):58–65.
- Xenos ES, Freeman M, Stevens S, Cassada D, Pacanowski J, Goldman M. Covered stents for injuries of subclavian and axillary arteries. *Journal of Vascular Surgery* 2003;**38**(September (3)):451–4.
- Vinces FY, Sperling DC. Endovascular treatment of a combined pseudoaneurysm and arteriovenous fistula of the subclavian artery caused by a gunshot wound to the chest. *Journal of Thoracic and Cardiovascular Surgery* 2005;**130**(July (1)):225–7.
- Castelli P, Caronno R, Piffaretti G, Tozzi M, Lagana D, Carrafiello G, et al. Endovascular repair of the subclavian and axillary arteries. *Injury* 2005;**36**(June (6)):778–82. [Epub 2005, March 28].
- Cipario S, Oggionio R, Mangano V, Bellandi G, Ercolini L, Michelagnoli S. An accidental subclavian artery cannulation: successful catheter removal by percutaneous vascular stenting. *Minerva Anestesiologica* 2007;**73**(April (4)):249–53. [Epub 2007, January 25].
- Bukhari HA, Saadia R, Hardy BW. Urgent endovascular stenting of subclavian artery pseudoaneurysm caused by seatbelt injury. *Canadian Journal of Surgery* 2007;**50**(August (4)):303–4.
- Stokkeland PJ, Soreide K, Fjetland L. Acute endovascular repair of right subclavian arterial perforation from clavicular fracture after blunt trauma. *Journal of Vascular and Interventional Radiology* 2007;**18**(May (5)):689–90.
- Piffaretti G, Tozzi M, Lomazzi C, Rivolta N, Caronno R, Lagana D, et al. Endovascular treatment for traumatic injuries of the peripheral arteries following blunt trauma. *Injury* 2007;**38**(September (9)):1091–7. [Epub 2007, May 31].
- Kapadia S, Parakh R, Grover T, Agarwal S, Yadav A. Endovascular covered stent for management of arterial pseudoaneurysms after central venous access. *Journal of Cardiothoracic and Vascular Anesthesia* 2007;**21**(February (1)):99–102. [Epub 2006, February 8].

22. Testerman GM, Gonzalez GD, Dale E. CT antigram and endovascular stent graft for an axillary artery gunshot wound. *Southern Medical Journal* 2008;**101**(August (8)):831–3.
23. Derom A, Ottenheim S, Raat H, van Kleef J. Endovascular treatment of acute subclavian pseudo-aneurysm after fracture of the clavicle. *Acta Chirurgica Belgica* 2008;**108**(July–August (4)):441–3.
24. du Toit DF, Lambrechts AV, Stark H, Warren BL. Long-term results of stent graft treatment of subclavian artery injuries: management of choice for stable patients? *Journal of Vascular Surgery* 2008;**47**(April (4)):739–43. [Epub 2008, February 1].
25. Cohen JE, Rajz G, Gomori JM, Verstandig A, Berlitzky Y, Anner H, et al. Urgent endovascular stent-graft placement for traumatic penetrating subclavian artery injuries. *Journal of the Neurological Sciences* 2008;**272**(September (1–2)):151–7. [Epub 2008, July 22].
26. Pikwer A, Acosta S, Kolbel T, Malina M, Sonesson B, Akeson J. Management of inadvertent arterial catheterisation associated with central venous access procedures. *European Journal of Vascular and Endovascular Surgery* 2009;**38**(December (6)):707–14. [Epub 2009, October 3].
27. Michaluk BT, Deutsch E, Moufid R, Panetta TF. Endovascular repair of an axillary pseudoaneurysm attributed to hyperextension injury. *Annals of Vascular Surgery* 2009;**23**(May–June (3)): 412.e5–9 [Epub 2008, October 2].
28. Cayne NS, Berland TL, Rockman CB, Maldonado TS, Adelman MA, Jacobowitz GR, et al. *Annals of Vascular Surgery* 2010;**24**(January (1)):44–7. [Epub 2009, September 5].
29. Carrick MM, Morrison CA, Pham HQ, Norman MA, Marvin B, Lee J, et al. Modern management of traumatic subclavian artery injuries: a single institution's experience in the evolution of endovascular repair. *American Journal of Surgery* 2010;**199**(January (1)):28–34. [Epub 2009, June 11].
30. Chemelli AP, Wiedermann F, Klocker J, Falkensammer J, Straszak A, Czermak BV, et al. Endovascular management of inadvertent subclavian artery catheterization during subclavian vein cannulation. *Journal of Vascular and Interventional Radiology* 2010;**21**(April (4)):470–6. [Epub 2010, February 20].
31. Carrafeillo G, Lagana D, Mangini M, Fontana F, Chiara R, Filippo P, et al. Percutaneous treatment of traumatic upper-extremity arterial injuries: a single-center experience. *Journal of Vascular and Interventional Radiology* 2001;**22**(January (1)):34–9.
32. Stefanczyk L, Czeczotka J, Elgalal M, Sapeiha M, Rowinski O. A large posttraumatic subclavian artery aneurysm complicated by artery occlusion and arteriobronchial fistula successfully treated using a covered stent. *Cardiovascular and Interventional Radiology* 2001;**34**(February (Suppl. 2)):S146–9. [Epub 2010, August 10].
33. Shalhub S, Starnes BW, Hatsukami TS, Karmy Jones R, Tran NT. Repair of blunt thoracic outlet injuries: an evolution from open to endovascular approach. *Journal of Trauma* 2001;**71**(November (5)):E114–21.
34. Demetriades D, Chahwan S, Gomez H, Peng R, Velmahos G, Murray J, et al. Penetrating injuries to the subclavian and axillary vessels. *Journal of the American College of Surgeons* 1999;**188**(March (3)):290–5.
35. Johnson CA. Endovascular management of peripheral vascular trauma. *Seminars in Interventional Radiology* 2010;**27**(March (1)):38–43.
36. DuBose J, Recinos G, Teixeira PJ, Inaba K, Demetriades D. Endovascular stenting for the treatment of traumatic internal carotid arteries: expanding experience. *Journal of Trauma* 2008;**65**(December (6)):1561–6.
37. White R, Krajcer Z, Johnson M, Williams D, Bacharach M, O'Malley E. Results of a multicenter trial for the treatment of traumatic vascular injury with a covered stent. *Journal of Trauma* 2006;**60**(June (6)):L1189–95. discussion 1195–6.
38. White JM, Cannon JW, Stannard A, Markov NP, Spencer JR, Rasmussen TE. Endovascular balloon occlusion of the aorta is superior to resuscitative thoracotomy with aortic clamping in a porcine model of hemorrhagic shock. *Surgery* 2011;**150**(September (3)):L400–9.
39. Stannard A, Eliason JL, Rasmussen TE. Resuscitative endovascular balloon occlusion of the aorta (REBOA) as an adjunct for hemorrhagic shock. *Journal of Trauma* 2011;**71**(December (6)):1869–72.
40. Karkos CD, Mair R, Markose G, Fishwick G, London NJ, Naylor AR. Hybrid procedures combining open and endovascular surgical techniques for the management of subclavian artery injuries. *Journal of Trauma* 2007;**63**(November (5)):E107–10.
41. Meyer T, Merkel S, Lang W. Combined operative and endovascular treatment of a post-traumatic embolizing aneurysm of the subclavian artery. *Journal of Endovascular Surgery* 1998;**5**(February (1)):52–5.
42. Filis KA. Endovascular grafting as a complement to open surgery treatment for axillary and subclavian vascular injuries. *Southern Medical Journal* 2008;**101**(August (8)):781–2.
43. Danetz JS, Cassano AD, Stoner MC, Ivatury RR, Levy MM. Feasibility of endovascular repair in penetrating axillosubclavian injuries: a retrospective review. *Journal of Vascular Surgery* 2005;**41**(February (2)):246–54.
44. Lee GS, Brawley J, Hung R. Complex subclavian artery pseudoaneurysm causing failure of endovascular stent repair with salvage by percutaneous thrombin injection. *Journal of Vascular Surgery* 2010;**52**(October (4)):1058–60. [Epub 2010, July 17].
45. Watelet J, Clavier E, Reix T, Dourvrin R, Thomas P, Tesart J. Traumatic subclavian artery pseudoaneurysm periprocedural salvage of failed stent-graft exclusion using coil embolization. *Journal of Endovascular Therapy* 2001;**8**(April (2)): 197–201.